Agricultural chemistry.

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By Prof. S. W. Johnson.

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AGRICULTURAL CHEMISTRY—SOIL-ANALYSIS.

NOTICE OF THE AGRICULTURAL CHEMISTRY OF THE GEOLOGICAL SURVEYS OF KENTUCKY AND ARKANSAS.*

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In no country has there been so much popular appreciation of practical science as in the United States of America. Scarcely one of the States is without its volume or volumes of Geological and Natural History Reports, and though some of them have been content to confine the work to the merest outline of the general and industrial geology of their territory, and have expended but a few hundreds of dollars in the undertaking, others, like New York, have embraced all the branches of Natural Science in their survey, have prolonged the work of exploration or elaboration through many years, and have devoted money to these objects with unsparing hand.

The results of these surveys as they stand recorded in the numerous volumes published by the States and by the General Government, are of very unequal merit, as might be expected from the wide range of country explored, from the various degrees of interest and appreciation governing the many Legislatures which have authorized these labors and from the exceedingly unequal ability of the individuals charged with their execution.

These explorations have originated in all cases with our scientific men. It is their influence either brought to bear immediately upon the legislative bodies, or exerted less directly through cultivated and public spirited persons to whom the possible benefits of geological surveys have been explained—that has accomplished this vast work.

The enterprises of which we speak being sustained pecuniarily at the expense of the people, and depending from year to year in many cases upon the popular vote, it has been not only politic but right to exhibit at the outset the prospects of pecuniary return for the required outlay of means, as an inducement to support such undertakings. It has been no less proper in presenting the results of the surveys, to lay stress on the discoveries having industrial bearings which are the fruits of the work.

In those States where large quantities of metallic ores occur, the interest of capitalists engaged in mining has often sufficed to

* 1st, 2d, 3d and 4th Reports of the Geological Survey of Kentucky 1854-60: 2d Report of the Geological Reconnoisance of Arkansas, 1860: Agricultural Chemistry and Geology by Dr. D. D. Owen, principal Geologist, and Dr. Robert Peter, Chemical Assistant.

inaugurate a geological survey. In other states the agricultural sentiment has had to be operated upon.

Great results have been promised to agriculture from the applications of geology and chemistry, and a great deal of labor has been performed in the attempt to satisfy the hopes that have been thus excited.

The chief object of the present notice is to inquire what has been really accomplished for the good of the farmer, by the scientific surveys that have been hitherto prosecuted in this country.

The labors of Dr. Peter in connection with the Kentucky and Arkansas Surveys being the most recent and extended attempts of this kind, we shall make them the basis of our inquiries.

If we except a few pages of general remarks on the theory of vegetable nutrition, &c., which while useful to the practical readers of the Report contain no new facts or principles,—the whole effort of Dr. Peter has been concentrated on the analysis of soils, marls, rocks and ashes. He publishes in the four Kentucky Reports analyses of 375 soils, and in the Arkansas Report, 187, in all 562 soil analyses. Besides, we find the results of examinations of 145 rocks, shales, &c., and of 38 ashes of plants, making a grand total of 795 agricultural analyses.

The agricultural fruits of the surveys of Kentucky and Arkansas are then to be sought in these analyses.

It certainly will strike all that the amount of work performed by Dr. Peter is unusually great. It is now but six years since the Kentucky survey was commenced and in that time the Dr. has not only analyzed 795 soils, but has executed 516 analyses of ores, slags, mineral waters and coals, making an average of two analyses for every three days of this whole period. This labor Dr. Peter states he has accomplished with the help of one intelligent assistant, and by a special organization of his laboratory and his operations whereby the utmost economy of time was secured. We have had such experience of the advantages of a similar system, that we are not prepared to doubt that the chemist who adopts a plan of analysis which fully satisfies him, and from which he never departs, may execute such an amount of work. At the same time we must bear in mind that the only control Dr. Peter offers for the accuracy of his results is, that the sum of the weights of the separated ingredients equals their original conjoined weight, no time being allowed to repeat a determination, or to prove the purity of a precipitate.

The Analytical Process followed in these analyses is not by any means so minute and full as we should be warranted to expect, when their author declares (4th Ky. Rep., p. 57) that "such a work to be eminently useful must be thorough and exhaustive;" for soluble silica, chlorine, nitric acid and ammonia are not at all estimated, and the condition of the iron, whether protoxyd or peroxyd, is not noticed. It is worthy of notice that

carbonic acid and lime are always present in atomic proportions in the soils latterly analyzed, no excess of either ingredient being mentioned in the results. Carbonic acid however is not noticed in the description of the analytical process, and that figuring in the analyses does not appear to have been directly estimated, but to have come from the oxalic acid of the reagent shelf.

If, as might easily happen, the contrary not being proved, a portion of the lime dissolved by hydrochloric acid exists in these soils as silicate, sulphate or phosphate, then the assumption that it is united to carbonic acid introduces an error into the summing up (which in many cases is exactly 100) and shows that a quantity of some other ingredient has been overlooked.

For the estimation of phosphoric acid a highly modified form of Sonnenschein's process is employed, but our author does not give the figures which prove that his changes are improvements.

Admitting however that the analyses are correct—we next inquire what is their value—what useful deductions from them appear in these Reports.

In the introduction to Vol. i, Kentucky Survey, page 13, Dr. Owen says: "By consulting the numerous interesting results obtained by the chemical analyses of the soils embodied in the pages of this report, abundant evidence will be gathered of the vital necessity of wide dissemination amongst the farming community, of the knowledge to be obtained by a correct insight into their chemical constitution." In the same volume, page 373, Dr. Peter remarks that he was impressed "that when the composition of our Kentucky soils and minerals in general, is once accurately established, their applications to our wants and uses would be obvious to all well informed persons. He has therefore consumed the time mainly in the analyses, and made up his report principally of the results."

In the agricultural section of the Arkansas Survey, p. 47, Dr. Owen says:—"principally from chemical soil-analyses can the agriculturist form an intelligent opinion as to the comparative fertility of soils, and their suitability to the growth of certain plants, as well as judge what applications may be required in the way of lime, bone earth, plaster of Paris, ashes, or salts of potash, soda, &c."

Dr. Peter, in the same volume, page 166–7, observes:—"It is believed that by no other mode than by chemical analysis or by the more tedious and laborious method of actual experience, in cropping for a series of years and publishing a record of the same, can the actual nature, capabilities and value of the various soils of a State be presented to the public; and that by instituting this Geologico-Agricultural Survey, the State of Arkansas not only aids materially in the progress of the general science of the civilized world, and that of the soil in particular, but takes the most effectual mode of making known to the enlightened immigrant her agricultural riches. In this she has followed

the wise lead of the older state of Kentucky, in which, since the institution of her geological survey, the value of the land in the regions examined and reported on has been very greatly enhanced."

In the Agricultural Geology of Kentucky, Report 2d, p. 9, Dr. Owen says: "Placing implicit reliance on the capabilities of chemical science to indicate by the analyses of soils, the ingredients removed by the cultivation and harvesting of successive crops, it was hoped that by collecting samples of the virgin soil, and of the same soil from an adjacent old field, that not only the different substances assimilated out of the soil could be ascertained, but also the exact proportion of these so that the farmer might know precisely what must be restored to the land to bring back its original fertility."

These quotations sufficiently show what were the opinions which led our author to devote such an amount of labor to the analysis of soils, and indicate in general, what results were expected.

In the 2d Arkansas Report, p. 49 et seq., Dr. Owen "proceeds to explain in what way soil-analysis becomes of value to the farmer." He desires "to call particular attention to this subject, because the opinion has been expressed even in this year (1860), and by those having a high standing in the scientific world, that chemistry is incapable of conveying any useful information to the farmer by analyzing his soil."

On the six following pages of the 2d Ark. Rep., and on page 30 of the 4th Ky. Rep., Dr. Owen gives the most complete *résumé* of the teachings of soil-analysis which we are able to find in the five volumes before us, and as these are his latest writings on the subject, and as he then had the data of 389 analyses, viz. of 187 Arkansas soils and 202 in the three volumes of the Kentucky Report,—these being refrered to on the pages we are quoting from,—we are warranted in considering what he has here presented, as embodying the *strong points* in favor of soil-analysis. We will notice them separately as gathered from both Reports.

1st. "Any one who will take the trouble to inspect the analyses of the 187 Arkansas soils will see that the relative proportions of the eleven mineral constituents of these soils is very accurately given."—*2d Ark. Rep.*, p. 49.

If we admit fully that Dr. Peter's analyses represent with fair accuracy the composition of the two grammes of soil he experimented with in each instance, we do not therefore allow that the composition of "these soils" considered as representing geological formations, or large agricultural districts, or even single fields, is "very accurately given."

Here at the outset the distinguished gentlemen who have conducted the 'geologico-' and 'chemico-agricultural' part of the Kentucky and Arkansas surveys have taken for granted, what

being an error, overturns their whole reasoning, and renders their soil-analyses comparatively worthless.

Years ago, following the teachers of agricultural chemistry in this country and England, we believed that soil-analyses were adapted to be of exceeding use to farmers. Having practised analytical chemistry sufficiently to undertake the work, we proceeded, when on a vacation visit, to collect some farm soils for the purpose of applying our skill and knowledge. On putting down the spade and post-augur into the drift overlying the lowest Silurian of Northern New York, we were at once struck with the difficulty of procuring an average specimen. The soil for a depth varying from two to six inches was quite fine, but below that depth largely mixed with gravel. On comparing different samples taken from a small area, it was plain that the soil was not a fit subject for analysis. The relative quantities of organic matter as indicated by the color of the surface of small stones,—some quartz and granitic, others slate and limestone of several geological members,—were astonishingly variable. Here we found the soil sandy, there it was clay. To take a sample from one place was to do obvious injustice to the sixty-acre field. To take it from a dozen places would not render the selection of a fair sample any more certain. Then as to depth —was it proper to go down six inches, one foot, or how far? Had the field been a bed of iron ore, assays of a dozen samples taken from different parts would have indicated very satisfactorily the general value of the deposit, would have served as data for buying and selling the property, because the worth of an unworked bed of such ore depends less upon its content of iron than upon external circumstances which affect the extracting of the metal. Had the field been covered with rich dressed copper ore to the depth of six inches, it would have been necessary to divide it up into small parcels of a few tons, average these carefully and as carefully assay each one. No one would risk purchasing a hundred thousand tons of copper ore on the analysis of one or of a dozen samples, because it is impracticable to intermix or average such a mass of material as that a dozen samples shall accurately represent it.

We hold it therefore as the first objection to soil-analyses that to procure a specimen which accurately and *certainly* represent a field or district, is practically impossible in the majority of cases, *and if possible, requires a series of analyses to prove the fact.*

This argument applies with the greater force when we consider how small a proportion of the ingredients of a soil are of any immediate use in feeding crops. The really active nutrient matters of a soil are not reckoned by per cents nor by tenths of per cents, but by the minutest fractions.

A heavy crop of thirty-seven bushels of wheat, grain and straw included, removes from an acre of land but 300 lbs. total

of mineral matters. According to Dr. Peter's weighings on some of the Kentucky soils, we may assume, that taken to the depth of a foot, an acre of soil weighs 3,000,000 lbs. All that is removed by the heaviest wheat crop then in one year is but $\frac{1}{30,000}$, or 0·0033+ per cent.

It follows that the annual removal of the heaviest crop of wheat from a soil for 100 years diminishes its mineral matters by less than 0·4 per cent. If then, in the selection of a sample, the average composition is departed from to the amount of 4 parts in 1000, the analysis may misrepresent the soil, by the value of 3700 bushels of wheat per acre, or by what represents, so far as mineral ingredients can, the fertility of a century.

What freaks and accidents is not the soil-analyst the sport of? A bird, squirrel, or dog relieving nature at the spot where he collects his sample, innocently magnifies the phosphoric acid or alkalies of the surrounding thousand acres a hundred fold. The soil gathered toward the end of a long rain, whereby its soluble matters are carried deep into the subsoil, is declared poor, by analysis, whereas if taken after a fortnight of drought it might appear extraordinarily fertile. Boussingault found in his rich garden soil in June, during wet weather, 0·00034 per cent of nitric acid. In the following September, after a period of dryness, it contained 0·0093 per cent, or twenty-seven times as much as in June. This ingredient is indeed more liable to fluctuation in amount than any other, both because it is formed in the soil, and because it is not subject to the absorbent action which the soil exercises over most other of its soluble constituents; but the same variation occurs among the other ingredients according to the direction of the capillary movement of the soil-water, though in less degree.

Independently however of all considerations and calculations like the above, we have proof—evidence at least that supports these considerations, and has never been publicly refuted—that it is practically impossible to obtain average specimens of the soil. I refer to investigations made as long ago as 1846–9 under the direction of the Prussian "*Landes Oekonomie Collegium*," and reported by the distinguished Magnus. The account of these experiments is given in detail in Erdmann's Journal für Praktische Chemie, vol. xlviii, pp. 447 et seq.

The "*Landes Oekonomie Collegium*" at that time carried on systematic experiments in agriculture at fourteen distinct stations scattered through the Prussian domain. The trials which we now speak of, were made for the ostensible purpose of studying the exhaustion of the soil by cropping. The plan was to analyze the fourteen soils, the history of which for years previous was accurately known, then crop them with rape until "exhausted," then compare together the original composition of the soils with their composition after exhaustion, taking into account as well,

the composition of the crops removed. The research began with collecting and analyzing the soils. In order to meet as far as possible the difficulties of securing average specimens, equal portions of the soil of each field were taken with the spade at ten or twelve different points, and thoroughly intermixed; each sample was then passed through a sieve, the holes of which were two square lines in area, so as to remove all coarser stones, then again well worked over to complete the mixture. Of each sample three separate portions were analyzed, in most cases by different operators. The analyses were made by, or under the guidance of, the ablest chemists of Germany. They were made according to a prescribed scheme, and that there should be no reason to slight the work, the work was paid for. It is true that analytical chemistry was not so advanced in 1846 as now. It is true that the methods then practised for estimating phosphoric acid and some other substances were not as perfect as they now are; but for the most part the analyses then made are as accurate as any that could be executed to-day. It cannot be supposed for a moment that analysts like Rammelsberg, Bödecker, Genth, Debus, Knop, Heintz, Krocker, Marchand, Weidenbusch, Sonnenschein, Varrentrap, Weber, &c. &c., would by fault of method or by carelessness return anything but results that were accurate, as far as it was possible to make them such. We cannot suppose that their determinations of lime, oxyd of iron, potash and sulphuric acid, substances estimated then by the same methods that are now employed, would vary if they were supplied with homogeneous material to operate upon. But let us look at some of their figures. We tabulate a number of them taken at random:

Soil of		Lime.	Potash.	Sulphuric acid.	Phosphoric acid.
Eldena,	*a.*	0·39	0·93	0·08	0·06
	b.	0·75	2·06	——	0·17
	c.	0·25	0·12	0·02	0·40
Beesdau,	*a.*	0·802	3·825	——	0·042
	b.	0·039	0·490	——	0·046
	c.	0·715	0·792	0·004	0·007
Neuensund,	*a.*	1·692	3·531	0·050	0·051
	b.	0·614	1·289	0·038	0·010
	c.	0·728	1·243	0·241	0·121
Turwe,	*a.*	2·312	1·112	0·040	0·057
	b.	2·67	1·14	0·03	0·20
	c.	3·391	0·201	0·022	0·014
Frankenfelde,	*a.*	0·420	1·155	0·016	0·004
	b.	1·081	——	——	0·418
	c.	0·461	1·456	0·015	0·071

If we run over these figures and those of the entire series of analyses, we find that different determinations disagree to such an extent as to make it the sheerest folly to base any calculation

of the value of the soil upon analysis. Some of the analyses agree sufficiently to show that accordant results are possible if uniform material be taken; but the grand result of the investigation is that the difficulties of getting a uniform material are exceedingly great. Again, we must remember that in the case before us, the three examinations of each soil were made upon portions of one carefully mixed sample. What would have been the result had each chemist received a sample collected separately from all the others, and from different parts of the field!

Dr. Peter mentions these analyses of the *Landes Collegium*, and quotes a few of the results on page 187 of the 3d Kentucky Report. He believes however that these discordant results do not invalidate soil analyses when made as they may be made with "means and appliances *now* at the service of the analytical chemist" and thinks "this statement however hazardous it may seem will be found to be sustained" in his Report.

In the Report before us however we do not find anything to sustain Dr. Peter's view. He gives, so far as we have discovered, no duplicate analyses, to show what accuracy his methods admit of on the same sample, much less does he prove by analyses of specimens separately gathered from the same field, that it is easy to procure an average material for analysis. Until this proof is produced the evidence is in favor of our view.

Having shown how small an error in sampling may affect the chemist's estimate of a soil, it is not out of place to insist for a moment, that a similar error in the analysis itself, must have the same result. In running over 200 pages of Dr. Peter's 4th Kentucky Report, we find five analyses of soil in which there is a gain of from five to eight tenths per cent; we find twenty-three in which there is a loss exceeding five tenths per cent. In thirteen of the latter the loss is eight or more tenths, in eight instances the loss is one per cent or more, and in one case is one and eight-tenths per cent. We should scorn to notice little matters like these, errors which are inseparable from the best manipulation and the best processes, were it not that in soil analysis it is precisely the small quantities which alone have any importance.

We find in Dr. Peter's work, as in the work of all who have preceded him in the analysis of soils from Davy and Sprengel down, evidence that the best endeavors in this line of research are entirely incommensurate with the desired results.

It may be objected to this criticism of the analyses that the loss or gain must be distributed among the twelve ingredients determined. It is true that there is a probability that such distribution would be just; but this is by no means *certain*, and it is equally true that this being done there is still force in the criticism—for the four-tenths per cent of the soil which a cen-

tury of wheat crops would remove, likewise consists of twelve ingredients.

The 2d result of these analyses, according to Drs. Owen and Peter, is what the former (4th Ky. Rep., p. 33) declares to be "a general law" "now established," viz., "that *soil-analysis is capable of showing the exhaustion in land of the mineral food of plants by continual cropping.*"

To show the removal of soil-ingredients by cropping, the plan was followed of collecting soils from contiguous fields, one of which had been "cultivated" while the other was in its virgin state. On comparing the analyses it was found that in seventy-one* cases out of seventy-nine, a loss had occurred in the soil which had been in use without manure from ten to fifty years. In eight instances, however, the analysis failed to show such a result, owing to local causes, the soil of the old field being based on a sub-soil richer than was the virgin field, or the old field having received washings of more elevated lands, &c.

The admitted richness of the old over the new soil in these eight exceptional cases, is expressed by hundredths of per cent, e.g., soil Nos. 982, virgin, and 983, cultivated, differ by 0·066 per cent of potash. Soils 1144 and 1146 by 0·032 per cent of phosphoric acid. Soils 1204 and 1205 by 0·092 per cent phosphoric acid. Soils 1207 and 1208 by 0·033 per cent potash. Similar fractions likewise show the amount of deterioration in the other seventy-one cases. We adduce two instances pointed out by Dr. Peter in the 3d Kentucky Report, p. 207, and one given on p. 176 of the 2d Arkansas Report:

	Carb. of lime.	Magnesia.	Phosphoric acid.	Potash.
Virgin soil, No. 557,	0·345	0·335	0·181†	0·156
Old soil, No. 558,	0·215	0·465	0·103†	0·101
Difference,	0·130	0·130 gain.	0·078†	0·055
Virgin soil, No. 738,	0·180	0·444	0·179	0·256
Old field, No. 739,	0·145	0·388	0·163	0·179
Difference,	0·035	0·056	0·016	0·077
Virgin soil, No. 288,	0·121	0·371	0·127	0·116
Old field, No. 289,	0·021	0·371	0·053	0·097
Difference,	0·100	0·000	0·074	0·019

We were prepared to find these differences much larger. It is seen at a glance that they fall within the errors of Dr. Peter's own manipulation, and when we assert that of ten analyses of the most homogeneous material made by the same analyst under the most favorable circumstances, five would differ among each other by an amount equal to the quantities upon which this "natural law" is supported, we assert what every competent

* Misprinted *twenty*-one, on p. 31, 4th Kentucky Report.

† Misprinted on p. 207, 3d Ky. Rep., where the difference is made 0·045 instead of 0·078, as given above from the tabulated analyses.

analyst knows to be true, and what moreover pronounces most emphatically upon the value of such investigations.

It is therefore our conclusion, that while, as has long been known, the soil loses in mineral matter what the crop gains, it is doubtful if in any given case chemical analysis can indicate this difference with certainty, for the reasons that the accidents which affect analysis make the limits of inaccuracy, to cover more than the loss by years of cropping. When we take into account the changes that are constantly progressing in the soil when under cultivation—changes by which the disintegration is hastened, changes by which it is made in many instances more retentive of soluble matters—when we remember that most cultivated crops, although they carry off in seed, stem and foliage a quantity of mineral matters, yet derive these in part from a depth below the range of analysis, and in their roots or stubble, leave upon the surface, salts brought up from a considerable depth—we perceive that the problem is so complicated with compensations and variable quantities as to put it beyond the reach of quantitative chemical analysis.

If, in any case, soil-analysis does show or appear to show the exhaustion of the soil, it is however, the appeal to experience which *proves* it, and as this is the first, most obvious, and an entirely sufficient proof, we do not see the value of the "law" that has 10 per cent (eight-seventy-ninths) of exceptions, the existence of which like that of the rule itself, is only to be established by comparison with the plain agricultural fact.

In short, if we admit the result as Drs. Owen and Peter would have it—of what use or interest is it?

The 3d point, is that analysis shows "the peculiarities of the soils derived from different geological formations." Says Dr. Owen, "these analyses most distinctly show that certain geological formations impart to the soil more of the important mineral fertilizers than others." The reader will be able "to see that it is those formations which are composed of easily disintegrating materials, which, all other things being equal, yield the soils richest in phosphoric acid, lime and potash; and at the same time contain the quantity of alumina and oxyd of iron necessary to render them sufficiently retentive and attractive of atmospheric water and ammonia; therefore these soils are the best adapted for those grains and crops which require the largest proportion of these ingredients." "He will moreover be able to trace the gradual diminution in the proportion of the more important mineral ingredients, down from these extraordinarily fertile soils derived from the highly fossiliferous, argillo-calcareous beds of the lower Silurian, the Cretaceous and the Tertiary systems of the West; through the silico-calcareous soils of the upper Silurian, Devonian and Sub-Carboniferous limestone strata, in which fossils are either more sparingly distributed or, in some

cases almost wanting, and which are far less easy of decomposition; thence through the argillo-silicious soils of the Coal measures with only locally organic remains, and these chiefly of plants, down to the more purely silicious soils prevalent where the non-fossiliferous sandstones of the Coal measures and of the Millstone Grit, prevail to the exclusion of either shales or limestones and which afford the most unproductive soils as yet analyzed." While it is to be expected that rocks of complex origin rich in organic remains—which are evidences that the rocks themselves originally resulted from the deposition of the washings of fertile lands—should yield richer soils than sandstones or limestones, we do not see that analysis of the soil makes the fact more evident Knowledge of the composition of a rock enables us to judge in a general way of the value of the soil, so far as this depends upon chemical characters. We do not see what is gained by further analyses of the soil. It would appear that the cheap mental processes of deduction or inference may accomplish here in a moment all that an expensive analysis can show.

We fail moreover to perceive that analysis shows "the *peculiarities* of the soils derived from the different geological formations." In a cretaceous or limestone soil we of course expect to find much carbonate of lime, and in a sandstone or millstone grit soil much insoluble silica or silicates, but the quantities of phosphoric acid, potash and sulphuric acid do not appear to bear any definite relation to their geological origin. It is impossible to represent the composition of the soil of any geological formation by a typical statement of percentages, or to point out its peculiarities further than by an undefinable more or less. Although Kentucky and Arkansas lie mostly or altogether beyond the influence of drift, yet the action of running water in its constant passage from hill-top to valley has to a great degree obliterated from the soils those *peculiar* differences to be found among the rocks from which they have been derived.

A careful examination of the analyses recorded in the Arkansas survey shows that the average composition of the eight soils analyzed from the Lower Silurian and of the fourteen from the millstone grit, compare as follows, in regard to the more important ingredients:

	Carb. lime.	Magnesia.	Phosphoric acid.	Sulphuric acid.	Potash.
Lower Silurian, average of 8 soils,	0·533	0·485	0·184	0·052	0·355
Millstone grit, " 14 "	0·215	0·531	0·180	0·057	0·148

Here we see that the soils of the poorest formation are inferior to those of the richest only in carbonate of lime and potash. Of the soils of the millstone grit, nine are richer in carb. lime than the poorest of the Silurian, and five of the former contain more potash than the poorest of the latter. On the other hand but two of the Silurian soils have higher percentages of either carb.

lime or potash, than the richest soil of the millstone grit. If these figures demonstrate anything, it is the fact, that no geological formation has the absolute monopoly of either barren or fertile soils. If the analyses of Dr. Peter show the "peculiarities" of the soils of any geological age, then certainly these peculiarities are not remarkably peculiar!

On page 50 of the 2d Ark. Rep., Dr. Owen remarks as follows: "With the table of the composition of the ashes of plants to refer to, appended to this Report, and after becoming acquainted with the usual proportions of mineral constituents in an average soil, information which is easily acquired by looking over the table of soil analyses in this Report, it is easy for any individual to see, when he is provided with a reliable analysis of his soil, not only to what crop it is best adapted, but what kind of mineral fertilizers, if any, it requires as a manure, and how it compares in fertility to the various grades of soils from other farms and other states. Is not this knowledge of some value to the farmer?"

The above, we are of opinion, proceeded rather from the generous heart than from the critical brain of its lamented author. Had he attempted to *do* the things which he believed to be so easy, we are sure his statements would have lost somewhat of their directness and would have appeared in a form highly modified from the above. "The usual proportion of ingredients in an average soil." What is an average soil? Our only way of deciding what is such a soil consists in noting the average yield of soils. But the yield depends not alone on the soil, but upon climate, weather, tillage and various incidents and accidents. It depends not on the composition of the soil—not on the "proportion of ingredients" alone, but likewise on the condition of those ingredients, their state of combination, their solubility. It depends also on the physical characters of the soil, which determine the relations of the crop to the essential conditions of regulated heat and moisture. The soil is not less important to the plant in its function of home than in its function of food, the lodgings are of equal influence with the board. It is a nice work to balance these varying circumstances, many of which have as yet in our science, no shadow of a numerical expression, and then to say how many thousandths of a per cent of potash, lime, phosphoric acid, &c., belong to the "average soil."

Dr. Peter has indeed attempted to show the degree of availability of the elements of the soil by the following process. "A quantity, generally thirty grammes of the air-dried soil is placed in an eight-ounce strong vial, with a close fitting stopper, and the bottle is filled up with distilled water which has been charged with pure carbonic acid gas, under a pressure of about two atmospheres. The bottle is allowed to remain for about a

month at a temperature about that of summer heat." The matters thus dissolved were then analyzed as usual. These results have this value, they show that the water of the soil is capable of dissolving all the elements of the food of plants. They furnish moreover a *rough* comparative view of the available matters in different soils. Beyond this we cannot attach any value to them.

We now come to Dr. Owen's 4th result of soil-analyses, embodied in the above quotation, and repeated on p. 30 of the 4th Ky. Rep., viz: its power of indicating "the suitability of the soil for any particular crop." Closely related to this is the 5th item, viz., that analysis can show "what addition any soil, either uncultivated or cultivated, requires to render it productive and remunerative for any given crop; and, of course, the deficiency in the soil of one or more of the eleven elements determined by chemical analysis."

We cannot help feeling that the above assertions which are here made unqualifiedly, were intended to be understood with a large amount of reserve and subject to various conditions. Otherwise we must regard them quite unjustified, if not absurd. The chemical analysis of soil reveals nothing as to its tenacity or lightness, its porosity or retentiveness for water, yet these physical and mechanical conditions more than anything else determine the adaptation of a soil for any particular crop. The best grass lands are not the best wheat lands—and although it would scarcely be questioned that wheat requires a richer soil than grass in order to produce an average crop, and although as we know, it often happens that many successive hay crops may be removed from a meadow without sensible diminution of the yield, while uninterrupted cropping with wheat nearly always reduces the capacity of the soil in a very few years below a profitable point; yet each average hay crop removes from a field more of every ingredient of vegetation than the grain and straw together of an average harvest of wheat.

Such at least is the testimony borne by the most recent and trustworthy data. Dr. Anderson of Glasgow basing his calculations on the best analyses and on the extensive agricultural statistics gathered in late years by the Highland and Ag. Society of Scotland, makes the following estimate of the amount of the principal ingredients removed from an acre by average crops of seven staple British farm products. See table on next page.—*Trans. Highland and Ag. Soc.*, 1861, p. 568.

On comparing the amount of matters removed from an acre by the wheat and hay crops, we find that the latter requires four times as much potash, lime and sulphuric acid; twice as much silica and one-fifth more nitrogen.

Again we know that oats are raised on soils which are considered too poor for the profitable production of wheat, and the

	Produce per Imperial Acre.	Total Weight in lbs.	Total Mineral Matters.	Potash.	Soda.	Lime.	Magnesia.	Chlorine.	Sulphuric acid.	Phosphoric acid.	Silica.	Nitrogen.
Wheat—												
Grain, ...	28 bush. at 60 lb.	1680	34·12	10·11	1·20	1·04	4·80	....	0·32	16·22	0·43	29·20
Straw, ...	1 ton, 3 cwt.	2576	114·48	20·70	2·84	8·53	2·23	....	3·55	3·16	73·47	16·13
Total, ...		....	148·60	30·81	4·04	9·57	7·03	....	3·87	19·38	73·90	45·33
Barley—												
Grain, ...	33 bush. at 53 lb.	1749	44·24	9·40	0·30	0·76	3·10	1·12	0·85	15·52	13·19	34·98
Straw, ...	18 cwt.	2016	99·14	11·24	1·14	5·81	2·75	1·30	1·10	7·22	68·58	6·03
Total, ...		....	143·38	20·64	1·44	6·57	5·85	2·42	1·95	22·74	81·77	41·01
Oats—												
Grain, ...	34 bush. at 40 lb.	1360	48·89	11·00	....	5·31	4·04	0·20	....	26·07	2·27	27·54
Straw, ...	1 ton.	2240	143·53	30·71	6·10	10·29	5·50	5·55	5·18	7·35	72·85	14·10
Total, ...		....	192·42	41·71	6·10	15·60	9·54	5·75	5·18	33·42	75·12	41·64
Beans and Peas—												
Grain, ...	25 bush. at 60 lb.	1650	55·97	30·00	0·31	3·01	4·00	....	1·76	16·65	0·24	46·10
Straw, ...	1 ton.	2240	108·51	48·61	13·14	29·37	3·74	7·00	2·07	0·74	3·84	26·88
Total, ...		....	164·48	78·61	13·45	32·38	7·74	7·00	3·83	17·39	4·08	72·98
Turnips, ...	13½ tons.	30,240	213·75	57·35	44·71	28·60	4·65	10·35	39·02	22·57	6·50	60·48
Potatoes,.......	3 tons.	6720	55·58	28·92	2·85	1·20	2·11	3·21	10·24	5·76	1·29	26·00
Hay, ...	2½ tons.	5600	391·31	129·79	4·80	35·46	9·62	39·61	16·57	21·79	133·67	56·22

table shows us that an average crop of oats requires more of every mineral ingredient than is needful for a corresponding wheat crop.

In fact, wheat is the crop, to grow which continuously requires, according to universal agricultural experience, land richer than that needed for any other of the seven crops whose chemical statistics are given in Dr. Anderson's Table, and notwithstanding, with exception of barley and the potato-tuber, it removes the least from the soil.

The farmer knows that wheat delights in a deep, rather heavy soil, one which holds moisture well, and yet is not wet. Barley and oats flourish on soils that are too dry and light, and grass on those which are too wet for wheat.

But how does the matter stand when these external conditions are taken into account? Does not analysis aid us then in a good degree? Let us take a case similar to what has repeatedly occurred in actual practice. We have a soil which as the result of long cultivation or from natural deficiencies, is incapable of yielding a remunerative crop of wheat. Its texture is good, it has produced wheat abundantly, and needs nothing but a little of the right kind of manure to restore its power of giving a crop. We put upon it Peruvian guano at the rate of 300 lbs. per acre, and the harvest is a good one. The entire addition to the soil is but $\frac{300}{3000000}$ths = one hundredth per cent. The amounts of phosphoric acid, of alkaline earths and nitrogen added, are for each, but one six-hundredth per cent of the soil, taken to the depth of a foot. These quantities are rather minute for even the improved analysis of the present time to estimate successfully.

Calculations like this show that the chemist cannot discriminate by his analysis between; 1st, a soil which is unproductive from the temporary exhaustion of some of its available ingredients; 2d, the same soil which is rendered fertile again for a year by the use of 300 lbs. of guano; and 3d, the same, made over-rich so that nothing will grow on it, by an application of a ton of guano.

On page 18 of the 2d Ky. Rep., Dr. Owen remarks as follows: "During last summer a soil was collected in Bullit county, from an old field which had been fifty or sixty years in cultivation, and which will now no longer produce clover. I venture to predict that when the analysis of this soil shall be completed it will be found to be deficient in some of these constituents,* and the analysis will probably show what other green crop might succeed better for the renovation of such land."

On page 230 of the 3d Ky. Rep., Dr. Peter gives the analysis of this soil, and says, "The inability of this soil to produce clover

* The mineral ingredients of plants.

is explained by its very small proportion of lime, and rather small amount of sulphuric and phosphoric acids. The addition of plaster of Paris or some of the calcareous marls would probably restore it to the capability of supporting a clover crop."

The percentages of the ingredients which Dr. Peter considers deficient, are as follows:

Carbonate of lime, - - -	0·072 = lime 0·040
Sulphuric acid, - - -	0·055
Phosphoric acid, - - -	0·070

Small as are these quantities, the smallest of them, viz., that of lime, yet amounts to 1200 lbs. per acre, which is enough to supply 10 clover crops of 3 tons each, and as by the analysis it all exists in the form of carbonate, it must all be available. We know from the vegetation experiments of Boussingault, Ville, and Sachs, that plants are capable of absorbing from a limited amount of soil *the whole* of any soluble nutritive substance present, provided its quantity be no more than the plants require, and the other elements of fertility are at hand in excess.

Twelve or thirteen years ago, Dr. Anderson in his capacity of Chemist to the Highland and Ag. Society of Scotland, had occasion to investigate two soils which had become "clover-sick," and he caused them, together with similar adjacent soils which still produced clover, to be most minutely analyzed. Without reproducing his figures, which may be found in the Trans. of the Highland and Ag. Soc. for 1849–51, p. 204, we will merely quote some of the remarks which accompany the analyses: "The results of these analyses are certainly of an unexpected character, and appear to me to indicate that, in this instance the failure of the clover cannot have been dependent upon the chemical constitution of the soil. In both cases the results of the analyses of each pair do not present a greater difference than would be obtained from the analyses of two portions of soil from different parts of any field."

In the present year, Stoeckhardt (*Chemischer Ackersmann*, No. 2, 1861, p. 85), has published an account of several "clover-sick" soils from Schlanstaedt, which reveal to analysis a greater content of *every nutritive mineral ingredient* both soluble in water and in acids, than exists in another soil from Frankenstein which produces clover and wheat as well. What proves beyond a doubt that the inability of these soils to yield clover depends upon something besides their chemical constitution, is the fact that lucerne and esparsette still flourish upon them admirably, and further, clover itself, if sown with one of these last mentioned crops, succeeds very well.

A great truth in agriculture is this: Each kind of agricultural plant requires that its seeds be surrounded with certain conditions in order that they may germinate readily and healthfully, so

that when the mother cotyledons are exhausted, the young plants shall attack the stores of food in the soil with that vigor which is needful in order to appropriate them without hindrance.

The fact that winter wheat is more delicate and fastidious in its infancy than most other crops, is perhaps the main reason why it does not succeed well on many good lands, and why it cannot be continuously produced from the same soil, year after year. It is a matter of experience that wheat requires a rather firm seed-bed: beans, oats and mangold-wurzel approach wheat in their requirements, while barley, peas and turnips are best suited in a light tilth. On the other hand, climate, weather and tillage so influence the character of the soil, that even on light lands, wheat may find all the conditions of its growth. The bed which is produced by inverting a clover sod, and allowing it to consolidate by time and rains, or by passing a heavy roller over it, is eminently adapted to wheat, even on a rather light soil.

The fact that in the cases given above from Stoeckhardt, clover succeeded when sown with lucerne or esparsette, would indicate that, possibly, the condition of the seed-bed was the cause of failure.

These and other facts which might be adduced to almost any extent, indicate sufficiently that chemical analysis alone, even if we admit its full nicety and accuracy, can at the best furnish us with a knowledge of but a few of many conditions which must coöperate in profitable agricultural production, and as a consequence, its part in guiding the farmer is but very subordinate. Taking into the account its evident uncertainty and clumsiness when applied to estimating the minute quantities which affect vegetable growth, the part it can play becomes still more subordinate—we hesitate not to say, insignificant.

As we write, a fragment from a Scientific Journal brings to our notice a discovery which if real, strengthens our views in an unexpected manner. It is well known that iodine is so immensely diluted in sea-water—the soil of marine-plants—that none of our tests though they are among the most delicate, serve to detect it directly, and it is doubtful if it has been detected even in the highly concentrated mother liquors which remain after separating the crystallizable salts, yet the fuci find and accumulate it, and we must grant that it is present there for them, in sufficient quantity.

Again, Prince Salm Horstmar several years since, in his admirable researches on the influence of the individual mineral ingredients of plants on the development of oats and barley, found that he could not by any possibility exclude chlorine from his experimental plants. His soils and pots, the salts and water he fed his plants with were so purified that he could not detect this element in them, and yet he invariably discovered it in the

ashes of the plants. So too he found titanic acid in the produce grown on the most carefully purified soils. Now, it is mentioned in the "Chemical News" that he finds *a few hundredths of lithium are indispensable* to the ripening of barley. This element Bunsen has but recently shown to be everywhere distributed, yet it has been hitherto entirely unnoticed in all soil- and plant-analyses because of its occurrence in almost infinitesimal quantity.

It must be well borne in mind that Agriculture herself—so-called Practice—is able of her own resources to judge somewhat of the value of soils, is able to know if a soil be fertile or poor, is able to pronounce upon its adaptation to crops, and can to a certain extent decide what is a good manure for this or that field.

We are free to assert that the knowledge which is now to be gathered from experience, is able in ninety-nine cases out of one hundred, to give a more truthful verdict as to the capacity of a soil, that any amount of analysis, chemical, mechanical or otherwise, can do. We would give more for the opinion of an old intelligent farmer than for that of the most skilled chemist in most questions connected with farming. Doubtless the farmer would make some blunders from which chemistry might save him, but the chemist would be likely to do more violence to agriculture, than the farmer would to chemistry.

By these statements which may, but should not surprise some of our scientific friends, we merely intend to express an opinion as to the present relative position towards agriculture of those who regard the art from a chemical, and those who see it from an experimental point of view.

If any one has fuller and more inspiring notions of the importance of science in its applications to agriculture than we have, we desire to sit at his feet and share the higher *afflatus*. But our inspiration, if it be of the sort that works enduring benefit, must be based on clear ideas of the directions in which advance is possible and on a full perception of the difficulties that lie before us, and the means of overcoming them.

We have great faith that chemistry and that chemical analysis have done and are to do a work for agriculture, that shall lay that venerable art under everlasting obligations to the youthful science. But not by soil-analyses alone or mainly is this to be achieved. We do not assert that soil-analysis is worthless—we believe that the probabilities of its uselessness in direct application to practice are so great that we would rarely base any operations on it alone, and yet it may in many cases, promote science and give us data for conclusions that are of practical use. But for these purposes it must form part of a system of observations and trials, must be a step in some research, must stand not as the index to a barren fact, but as the revelator of fruitful ideas.

We hold that soil-analysis long ago played out the part which Dr. Peter would have it perform. In the hands of Sprengel it

was fertile with new truth, but it must henceforth be a tool for occasional use, and not an engine of discovery. With our advance in knowledge there must be an advance in methods of finding out the unknown. Soil-analysis was indeed a means of insight into the secrets of vegetable growth, but it carried with it the measure of its limit. What we call telescopes do not enable us to see *the end!*

To study the soil in the hope of benefitting agriculture, we must regard all its relations to the plant. We must examine it not merely from those points of view which theoretical chemistry suggests, but especially from those which a knowledge of practical agriculture furnishes. This is becoming more and more the habit of agricultural chemists and the results are of the happiest kind.

Let us remember what the illustrious Nestor of Agricultural Science, Boussingault, has said as the summing up of his protracted experience and study.

"At an epoch not far distant it was believed that a strict connexion existed between the composition and the quality of arable soil. Numerous analyses shortly modified this opinion as too positive. The sagacious Schübler even sought to prove in a research that has become classic, that the fertility of a soil depends more upon its physical properties, its state of aggregation, power of absorption, &c., than upon its chemical constitution."

"The physical properties, in my opinion, do not enable us, more than the chemical composition, to pronounce upon the degree of fertility of the soil. To decide this point with some measure of certainty, it is indispensable to have recourse to direct observation; it is necessary to cultivate a plant in the soil, and ascertain with what vigor it developes there: the analysis of the plant afterward intervenes usefully, to indicate the kind and quantity of the elements that have been assimilated."—("*De la Terre Végétale considerée dans ses Effets sur la Vegetation*," page 283 of "*Agronomie, Chimie agricole et Physiologie*, *Tome premier*, 1860.")

There has been much progress made in our knowledge of the soil during the last ten years. This advance has not consisted in revealing to us the presence of new elements (lithia perhaps excepted), nor in fixing with any more certainty the quantitative limits which separate barrenness from fertility, it has not shown what is the composition of a Silurian or a Sub-Carboniferous, a Drift or a Tertiary soil, it has not defined the soil adapted to wheat or that productive of clover, it has not indicated the manures which this or that soil needs; but content with the fact that all soils which naturally support vegetation contain the elements of vegetation, it has sought to ascertain in what forms these elements are assimilable, how they may be made available, what changes or reactions in the soil affect its productiveness; how fertilizers act indirectly (their influence often having no

relation to any supposable direct action), how the soil affects the life of the plant otherwise than by feeding it, &c. &c.

We are approaching in fact by slow degrees to an understanding of the physiological significance of the soil, a grand result to which chemistry and physics coöperate.

We trust that in the future, the American people will not less but more appreciate the value of science in its practical and especially its agricultural bearings; that here, as in Germany, France and England, the labors of those who seek to unite Practice with Science may be fostered and sustained. But to this end scientific men must be cautious that in endeavoring to help, however honestly and laboriously they may work, they do not hinder.

Sheffield Scientific School, August 20th, 1861.